

traveling down the throat into the gas stream. PM carried along with the gas stream impacts on these water particles and on the water wall. As the scrubber water and flue gas leave the venturi section, they pass into the flooded elbow, where the stream velocity decreases, allowing the water and gas to separate. By restricting the throat area within the venturi, the linear gas velocity is increased and the pressure drop is subsequently increased, increasing PM removal efficiency.

At the base of the flooded elbow, the gas stream passes through a connecting duct to the base of the impingement tray tower. Gas velocity is further reduced upon entry to the tower as the gas stream passes upward through the perforated impingement trays. Water usually enters the trays from inlet ports on opposite sides and flows across the tray. As gas passes through each perforation in the tray, it creates a jet that bubbles up the water and further entrains solid particles. At the top of the tower is a mist eliminator to reduce the carryover of water droplets in the stack effluent gas. The impingement section can contain from one to four trays.

In the case of MHFs, afterburners may be utilized to achieve additional reduction of organic emissions, including benzene. MHFs produce more benzene emissions because they are designed with countercurrent air flow. Because sludge is usually fed into the top of the furnace, hot air and wet sludge feed are contacted at the top of the furnace, such that any compounds distilled from the solids are immediately vented from the furnace at temperatures too low to completely destroy them.

Utilization of an afterburner provides a second opportunity for these unburned hydrocarbons to be fully combusted. In afterburning, furnace exhaust gases are ducted to a chamber, where they are mixed with supplemental fuel and air and completely combusted. Additionally, some incinerators have the flexibility to allow sludge to be fed to a lower hearth, thus allowing the upper hearth(s) to function essentially as an afterburner.

7.2.4 Regulatory Analysis

Prior to 1993, organic emissions from SSIs were not regulated. On February 19, 1993, Part 503 was added to Subchapter O in Chapter I of Title 40 of the CFR, establishing standards for use or disposal of sewage sludge. Subpart E of Part 503 regulates emissions of total hydrocarbons (THC) from the incineration of SSIs and applies to all SSIs. The THC limit of 100 ppm (measured as a monthly average) is a surrogate for all organic compounds, including benzene. In establishing a standard for organic emissions, EPA had considered establishing a standard for 14 individual organic compounds, including benzene; however, it was concluded that the individual organic pollutants were not significant enough a factor in sewage sludge to warrant requiring individual pollutant limits. Furthermore, based on a long-term demonstration of heated flame ionization detection systems monitoring organic emissions from SSIs, it was concluded that there is an excellent correlation between THC emission levels and organic pollutant emission levels.

The THC limit established in Part 503 is an operational standard that would, in general, not require the addition of control devices to existing incinerators, but would require incinerators to adopt good operating practices on a continuous basis. It is expected that FBCs and MHFs will have no difficulty meeting the standard.²⁰⁰ To ensure the adoption of GCP, the standard requires continuous THC monitoring using a flame ionization detection system, continuous monitoring of the moisture content in the exit gas, and continuous monitoring of combustion temperature.

7.3 HAZARDOUS WASTE INCINERATION

Hazardous waste is produced in the form of liquids (e.g., waste oils, halogenated and nonhalogenated solvents, other organic liquids, and pesticides/ herbicides) and sludges and solids (e.g., halogenated and nonhalogenated sludges and solids, dye and paint sludges, resins, and latex). Based on a 1986 study, total annual hazardous waste generation in the United States was approximately 292 million tons (265 million metric tons).²⁰¹ Only a

small fraction of the waste (<1 percent) was incinerated. The major types of hazardous waste streams incinerated were spent nonhalogenated solvents and corrosive and reactive wastes contaminated with organics. Together, these accounted for 44 percent of the waste incinerated. Other prominent wastes included hydrocyanic acid, acrylonitrile bottoms, and nonlisted ignitable wastes.

Hazardous waste can be thermally destroyed through burning under oxidative conditions in incineration systems designed specifically for this purpose and in various types of industrial kilns, boilers, and furnaces. The primary purpose of a hazardous waste incinerator is the destruction of the waste; some systems include energy recovery devices. An estimated 1.9 million tons (1.7 million Mg) of hazardous waste were disposed of in incinerators in 1981.²⁰¹ The primary purpose of industrial kilns, boilers, or furnaces is to produce a commercially viable product such as cement, lime, or steam. An estimated 230 million gallons of waste fuel and waste oil were treated at industrial kilns, boilers, and furnaces in 1983.²⁰¹ In 1981, it was estimated that industrial kilns, boilers, and furnaces disposed of more than twice the amount of waste that was disposed of via incinerators.²⁰¹

7.3.1 Process Description: Incineration

Incineration is a process that employs thermal decomposition via thermal oxidation at high temperatures (usually 1,650°F [900°C] or greater) to destroy the organic fraction of the waste and reduce volume. A study conducted in 1986 identified 221 hazardous waste incinerators operating under the Resource Conservation and Recovery Act (RCRA) system in the United States. (See Section 7.3.5 for a discussion of this and other regulations applicable to hazardous waste incineration.) These incinerators are located at 189 separate facilities, 171 of which are located at the site of waste generation.²⁰¹

A diagram of the typical process component options in a hazardous waste incineration facility is provided in Figure 7-7.²⁰¹ The diagram shows that the major subsystems that may be incorporated into the hazardous waste incineration system are (1) waste

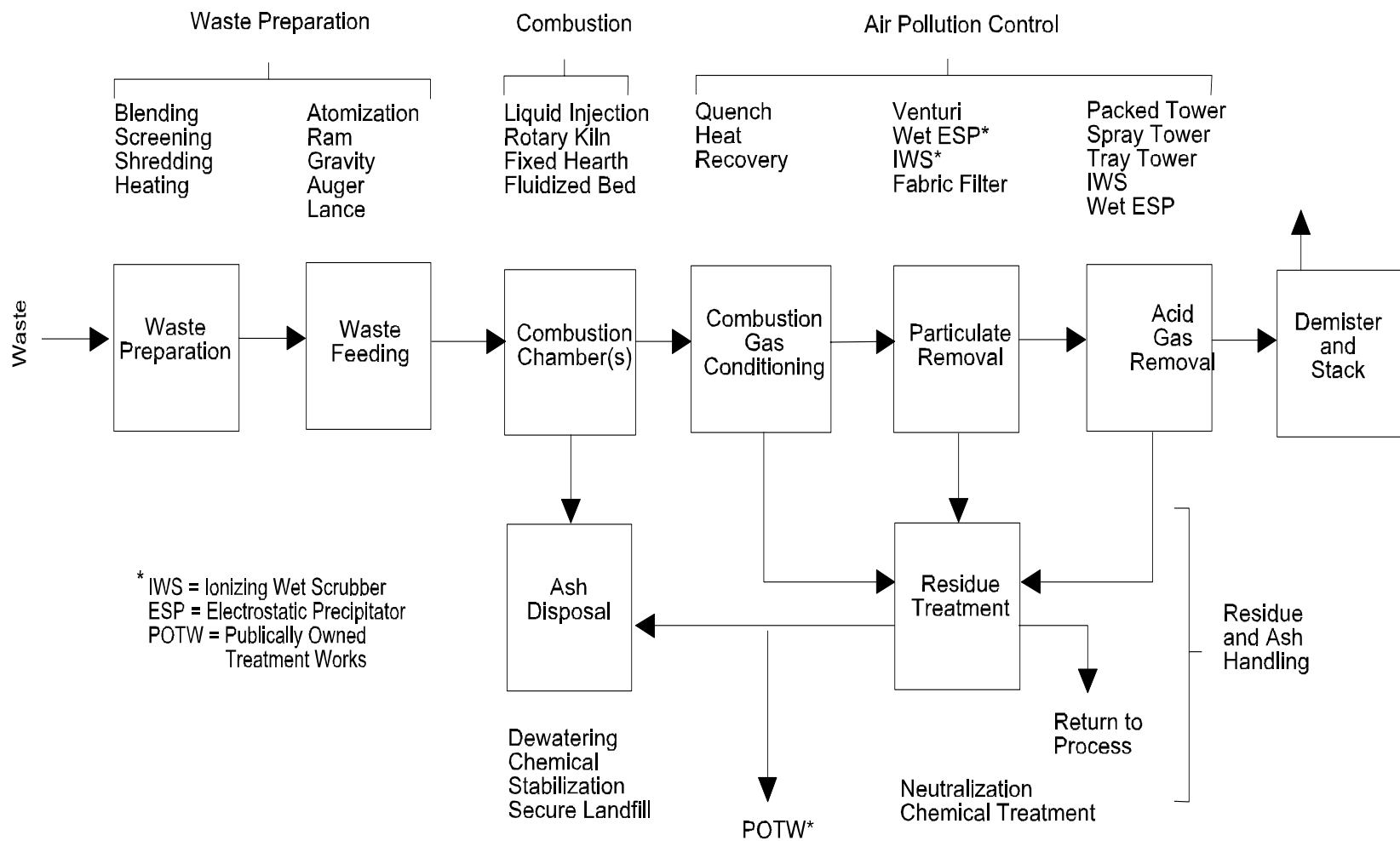


Figure 7-7. General Orientation of Hazardous Waste Incineration Subsystems and Typical Component Options

Source: Reference 201.

preparation and feeding, (2) combustion chamber(s), (3) air pollution control, and (4) residue/ash handling. These subsystems are discussed in this section, except that air pollution control devices are discussed in Section 7.3.4 of this section.

Additionally, energy-recovery equipment may be installed as part of the hazardous waste incineration system, provided that the incinerator is large enough to make energy recovery economically productive (i.e., bigger than about 7 million Btu/hour [7.4 million kJ/hour]) and that corrosive constituents (e.g., HCl) and adhesive particulates are not present at levels that would damage the equipment.²⁰²

Additionally, a few other technologies have been used for incineration of hazardous waste, including ocean incineration vessels and mobile incinerators. These processes are not in widespread use in the United States and are discussed only briefly.

Waste Preparation and Feeding²⁰¹

The feed method is determined by the physical form of the hazardous waste. Waste liquids are blended and then pumped into the combustion chamber through nozzles or via atomizing burners. Liquid wastes containing suspended particles may need to be screened to avoid clogging of small nozzle or atomizer openings. Liquid wastes may also be blended in order to control the heat content of the liquid to achieve sustained combustion (typically to 8,000 Btu/lb [18,603 kJ/kg]) and to control the chlorine (Cl₂) content of the waste fed to the incinerator (typically to 30 percent or less) to limit the potential for formation of hazardous-free Cl₂ gas in the combustion gas.

Waste sludges are typically fed to the combustion chamber using progressive cavity pumps and water-cooled lances. Bulk solid wastes may be shredded to control particle size and may be fed to the combustion chamber via rams, gravity feed, air lock feeders, vibratory or screw feeders, or belt feeders.

Combustion Chambers^{201,202}

The following five types of combustion chambers are available and operating today:²⁰²

- Liquid injection;
- Rotary kiln;
- Fixed-hearth;
- Fluidized-bed; and
- Fume.

These five types of combustion chambers are discussed below.

Liquid injection--Liquid injection combustion chambers are applicable almost exclusively for pumpable liquid waste, including some low-viscosity sludges and slurries. The typical capacity of liquid injection units is about 8 to 28 million Btu/hour (8.4 to 29.5 million kJ/hr). Figure 7-8 presents a typical schematic diagram of a liquid-injection unit.²⁰¹

Liquid injection units are usually simple, refractory-lined cylinders (either horizontally or vertically aligned) equipped with one or more waste burners. Vertically aligned units are preferred when wastes are high in organic salts and fusible ash content; horizontal units may be used with low-ash waste. Liquid wastes are injected through the burner(s), atomized to fine droplets, and burned in suspension. Burners and separate waste injection nozzles may be oriented for axial, radial, or tangential firing. Good atomization, using gas-fluid nozzles with high-pressure air or steam or with mechanical (hydraulic) means, is necessary to achieve high liquid waste destruction efficiency.

Rotary Kiln--Rotary kiln incinerators are applicable to the destruction of solid wastes, slurries, containerized waste, and liquids. Because of their versatility, they are most

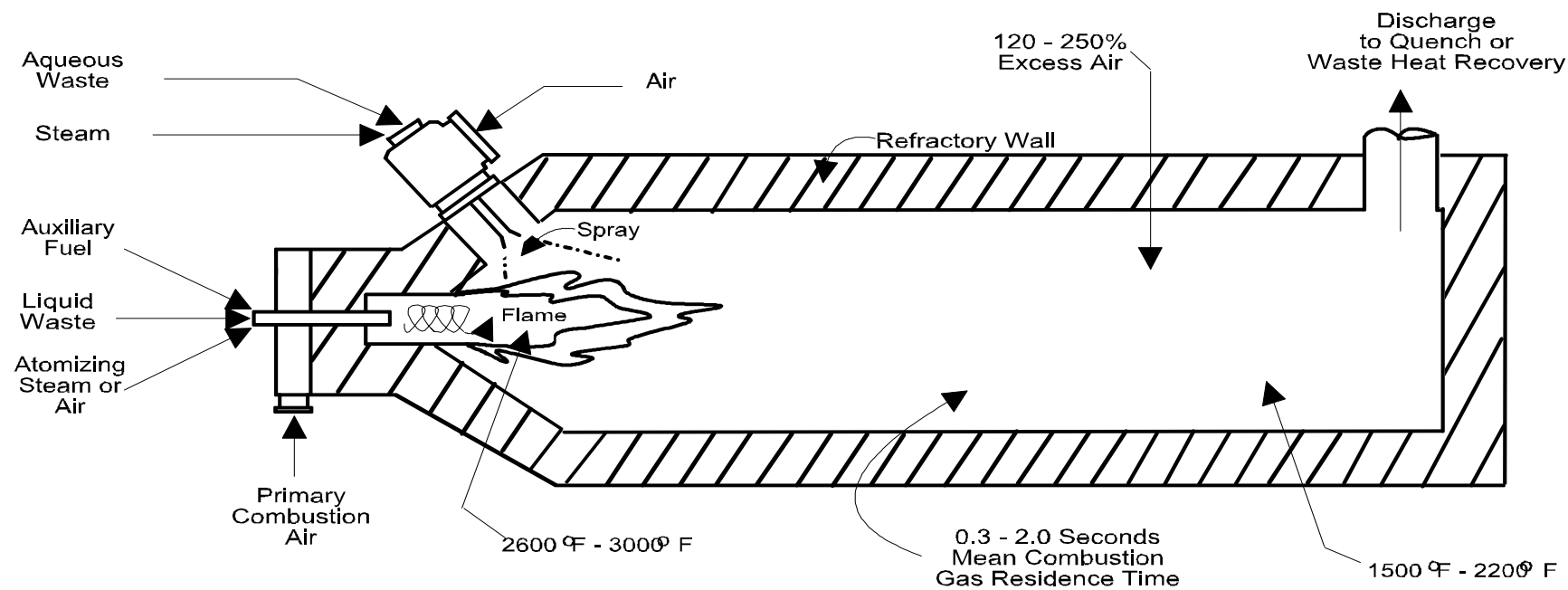


Figure 7-8. Typical Liquid Injection Combustion Chamber

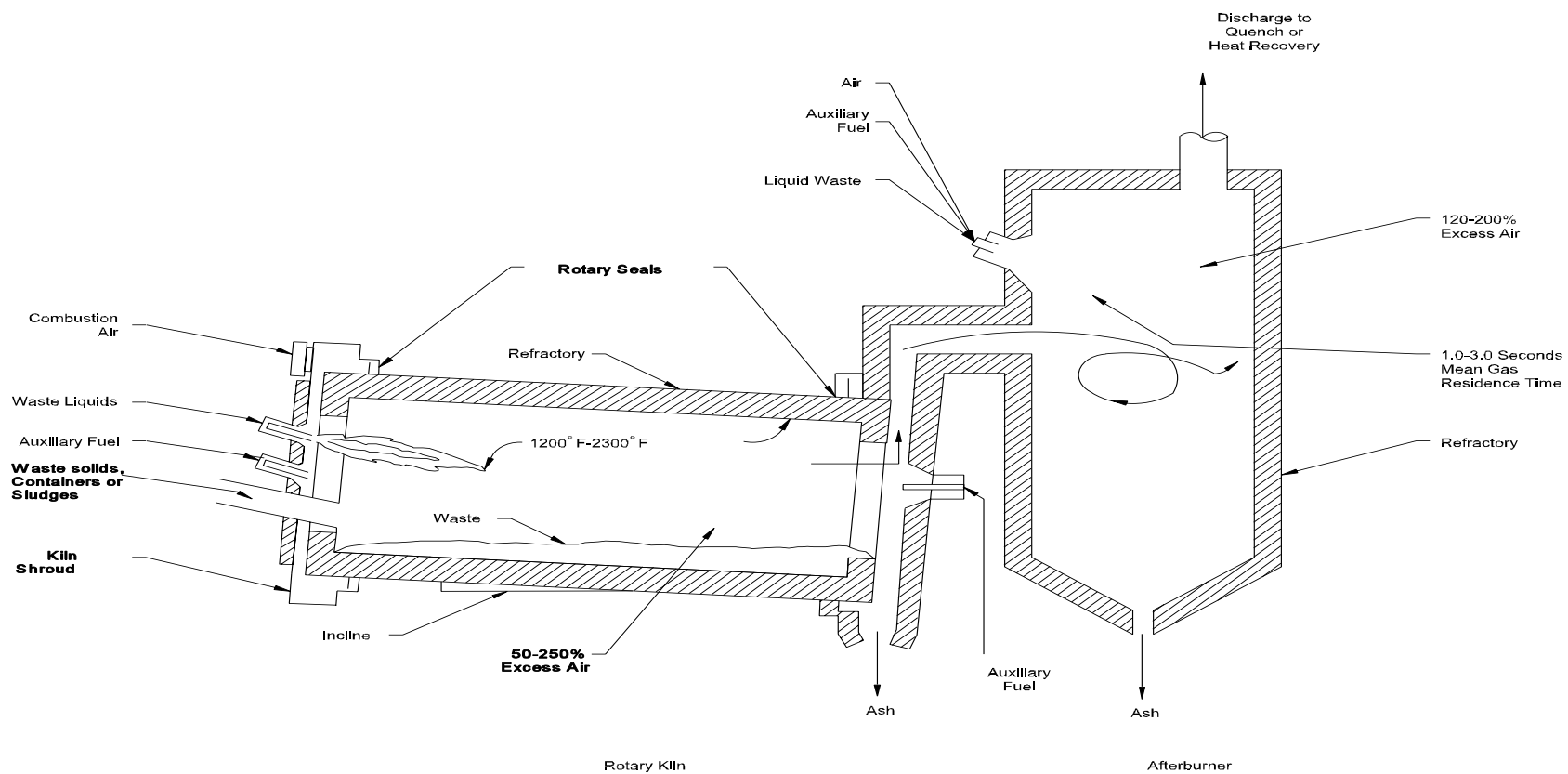
Source: Reference 201.

frequently used by commercial off-site incineration facilities. The typical capacity of these units is about 10 to 60 million Btu/hour. Figure 7-9 presents a typical schematic diagram of a rotary kiln unit.²⁰¹

Rotary kiln incinerators generally consist of two combustion chambers: a rotating kiln and an afterburner. The rotary kiln is a cylindrical refractory-lined shell that is mounted on a slight incline. The incline facilitates ash and slag removal. Rotation of the shell provides transportation of the waste through the kiln and enhances mixing of the waste with combustion air. The rotational speed of the kiln is used to control waste residence time and mixing. The primary function of the kiln is to convert solid wastes to gases, which occurs through a series of volatilization, destructive distillation, and partial combustion reactions.

An afterburner is connected directly to the discharge end of the kiln. The afterburner is used to ensure complete combustion of flue gases before their treatment for air pollutants. A tertiary combustion chamber may be added if needed. The afterburner itself may be horizontally or vertically aligned, and functions much on the same principles as the liquid injection unit described above. Both the afterburner and the kiln are usually equipped with an auxiliary fuel-firing system to control the operating temperature.

Fixed-Hearth--Fixed-hearth incinerators, also called controlled-air, starved-air, or pyrolytic incinerators, are the third major technology used for hazardous waste incineration. This type of incinerator may be used for the destruction of solid, sludge, and liquid wastes. Fixed-hearth units tend to be of smaller capacity (typically 5 million Btu/hr [5.3 million kJ/hr]) than liquid injection or rotary kiln incinerators because of physical limitations in ram-feeding and transporting large amounts of waste materials through the combustion chamber. Lower relative capital costs and reduced particulate control requirements make fixed-hearth units more attractive than rotary kilns for smaller on-site installations. Figure 7-10 presents a typical schematic diagram of a fixed-hearth unit.²⁰¹



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Figure 7-9 Typical Rotary Kiln/Afterburner Combustion Chamber

Source: Reference 201.

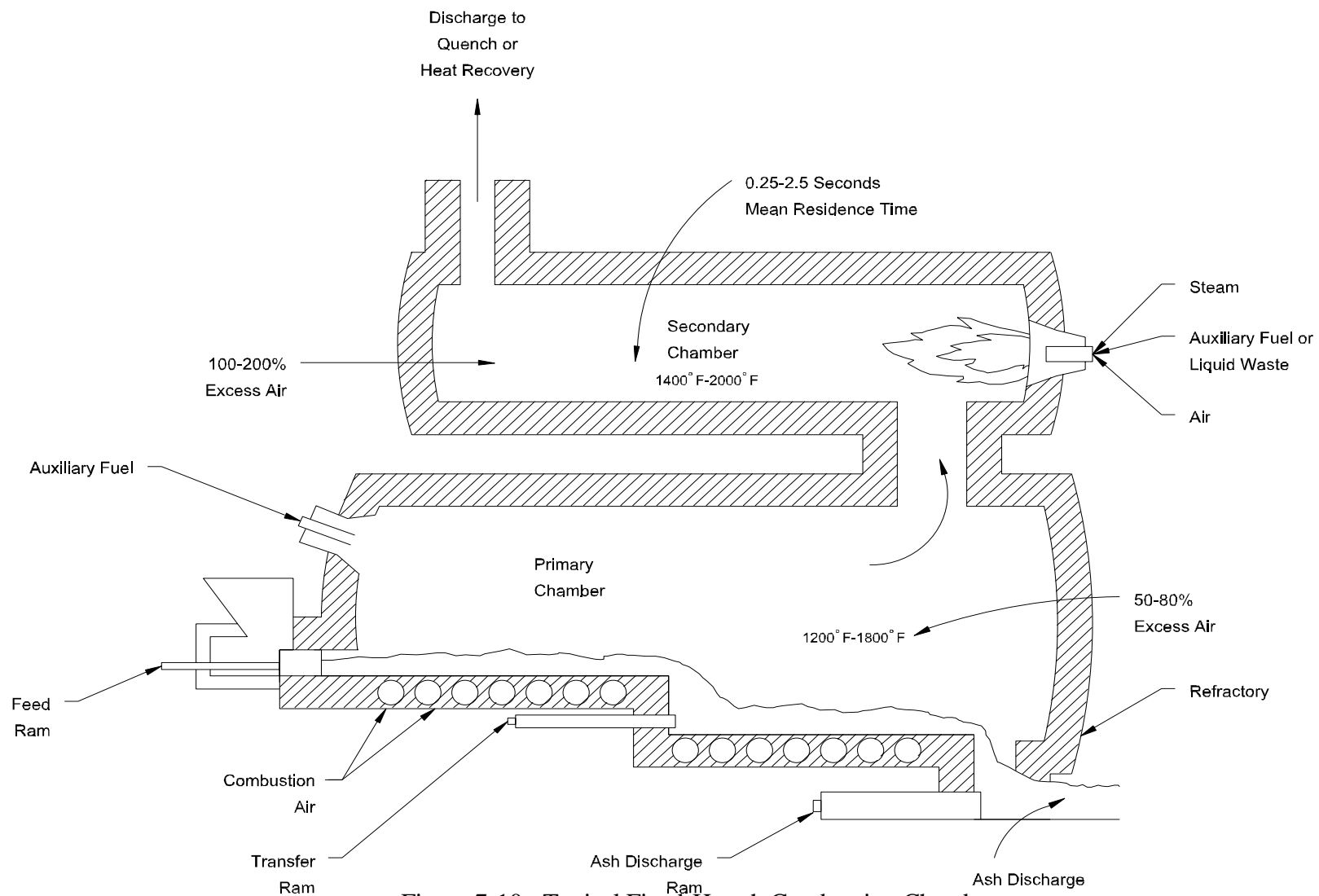


Figure 7-10. Typical Fixed-Hearth Combustion Chamber

Source: Reference 201.

Fixed-hearth units consist of a two-stage combustion process similar to that of rotary kilns. Waste is ram-fed into the primary chamber and burned at about 50 to 80 percent of stoichiometric air requirements. This starved-air condition causes most of the volatile fraction to be destroyed pyrolytically. The resultant smoke and pyrolytic products pass to the secondary chamber, where additional air and, in some cases, supplemental fuel, are injected to complete the combustion.

Fluidized-Bed--FBCs have only more recently been applied to hazardous waste incineration. FBCs may be applied to solids, liquids, and gases; however, this type of incinerator is most effective for processing heavy sludges and slurries. Solids generally require prescreening or crushing to a size less than 2 inches in diameter. The typical capacity of this type of incinerator is 45 million Btu/hr (47.5 million kJ/hr). See Figure 7-4 of this chapter for a typical schematic diagram of an FBC chamber.

FBC chambers consist of a single refractory-lined combustion vessel partially filled with inert granular material (e.g., particles of sand, alumina, and sodium carbonate). Combustion air is supplied through a distributor plate at the base of the combustor at a rate sufficient to fluidize (bubbling bed) or entrain (circulating bed) the bed material. The bed is preheated to startup temperatures by a burner. The bed material is kept at temperatures ranging from 840 to 1,560°F (450 to 850°C). Wastes are injected into the combustion chamber pneumatically, mechanically, or by gravity. Solid wastes are fed into the combustion chamber through an opening above the fluidized bed (similar to the opening for sand feed, represented in Figure 7-4). Liquid wastes are fed into the bottom of the fluidized bed (represented in Figure 7-4 as the opening designated for sludge feed). As the waste is fed to the combustion chamber, heat is transferred from the bed material to the wastes. Upon combustion, the waste returns heat to the bed. The high temperature of the bed also allows for combustion of waste gases above the bed.

Fume--Fume incinerators are used exclusively to destroy gaseous or fume wastes. The combustion chamber is comparable to that of a liquid-injection incinerator

(Figure 7-8) in that it usually has a single chamber, is vertically or horizontally aligned, and uses nozzles to inject the waste into the chamber for combustion. Waste gases are injected by pressure or atomization through the burner nozzles. Wastes may be combusted solely by thermal or catalytic oxidation. If no catalyst is used, the combustion chamber temperature is maintained at 1,200 to 1,800°F (650 to 980°C). If a catalyst is used (e.g., alumina coated with noble metals, such as platinum or palladium, and other metals, such as copper chromate or manganese), the temperature may be maintained at lower temperatures of 500 to 900°F (260 to 480°C).

Residue and Ash Handling²⁰¹

Residue and ash consist of the inorganic components of the hazardous waste that are not destroyed by incineration. Bottom ash is created in the combustion chamber and residue collects in the air pollution control devices. After discharge from the combustion chamber, bottom ash is commonly air-cooled or quenched with water. The ash is then accumulated on site in storage lagoons or in drums prior to disposal to a permitted hazardous waste land disposal facility. The ash may also be dewatered or chemically fixated/stabilized prior to disposal.

Air pollution control residues are typically aqueous streams containing PM, absorbed acid gases, and small amounts of organic material. These streams are collected in sumps or recirculation tanks, where the acids are neutralized with caustic and returned to the process. When the total dissolved solids in the aqueous stream exceeds 3 percent, a portion of the wastes is discharged for treatment and disposal.

Ocean Incinerators

Ocean incineration involves the thermal destruction of liquid hazardous wastes at sea in specially designed tanker vessels outfitted with high-temperature incinerators. Ocean incinerators are identical to land-based liquid injection incinerators, except that current ocean

incinerators are not equipped with air pollution control systems. Largely due to public concern over potential environmental effects, ocean incineration of hazardous waste has not been used on a routine basis in the United States.²⁰¹

Mobile Incinerators

Mobile incinerators have been developed for on-site cleanup at uncontrolled hazardous waste sites. Most of these systems are scaled-down, trailer-mounted versions of a conventional rotary kiln or an FBC, with thermal capacities ranging from 10 to 20 million Btu/hr (10.5 to 21.1 million kJ/hr). The performance of these mobile systems has been shown to be comparable to equivalent stationary facilities. Because of their high cost, these types of systems are considered to be cost-effective only at waste sites where large amounts of contaminated material (e.g., soil) would need to be transported off site.²⁰¹

7.3.2 Industrial Kilns, Boilers, and Furnaces

Industrial kilns, boilers, and furnaces burn hazardous wastes as fuel to produce commercially viable products such as cement, lime, iron, asphalt, or steam. These industrial sources require large inputs of fuel to produce the desired product. Hazardous waste, which is considered an economical alternative to fossil fuels for energy and heat, is utilized as a supplemental fuel. In the process of producing energy and heat, the hazardous wastes are subjected to high temperature for a sufficient time to destroy the hazardous content and the bulk of the waste.

Based on a study conducted in 1984, there were over 1,300 facilities using hazardous waste-derived fuels (HWDF) in 1983, accounting for a total of 230 million gallons (871 million liters) of waste fuel and waste oil per year. Although the majority (69 percent) of HWDF is burned by only about 2 percent of the 1,300 facilities (i.e., medium- to large-size industrial boilers, cement and aggregate kilns, and iron-making furnaces), other industries burning significant quantities of HWDF included the paper (SIC 26), petroleum (SIC 29),

primary metals (SIC 33), and stone, clay, glass, and concrete (SIC 32) industries.²⁰¹ Industrial boilers and furnaces, iron foundries, and cement kilns are described in more detail in Sections 7.4, 7.7, and 7.8, respectively, of this document.

7.3.3 Benzene Emissions From Hazardous Waste Incineration

There are limited data documenting benzene emissions from hazardous waste incinerators. However, as discussed below, benzene is one of the most frequently identified products of incomplete combustion (PICs) in air emissions from hazardous waste incinerators.²⁰³ Two emission factors for benzene emissions are provided in Table 7-4.

7.3.4 Control Technologies for Hazardous Waste Incineration

Most organics control is achieved by promoting complete combustion by following GCP. The general conditions of GCP are summarized in Section 7.1.3. Again, failure to achieve complete combustion of organic materials evolved from the waste can result in emissions of a variety of organic compounds. Benzene is one of the most frequently identified PICs in air emissions from hazardous waste incinerators.²⁰³

In addition to adequate oxygen, temperature, residence time, and turbulence, control of organics may be partially achieved by using acid gas and PM control devices; however, this has not been documented. The most frequently used control devices for acid gas and PM control are wet scrubbers and fabric filters. Fabric filters provide mainly PM control. Other PM control technologies include venturi scrubbers and ESPs. In addition to wet scrubbing, dry sorbent injection and spray dryer absorbers have also been used for acid gas (HCl and SO₂) control.

TABLE 7-4. SUMMARY OF BENZENE EMISSION FACTORS
FOR HAZARDOUS WASTE INCINERATION

SCC	Emission Source	Control Device	Emission Factor lb/ton (kg/Mg) ^a	Factor Rating
5-03-005-01	Liquid injection incinerator	Uncontrolled ^b	4.66×10^{-5} (2.33×10^{-5})	U
5-03-005-01	Liquid injection incinerator	Various control devices ^c	1.23×10^{-3} (6.16×10^{-4}) ^d	U

Source: Reference 3.

^a Factors are in lb (kg) of benzene emitted per ton (Mg) of waste incinerated.

^b The liquid injection incinerator has a built-in afterburner chamber.

^c The incinerators tested had the following control devices: venturi, packed, and ionized scrubbers; carbon bed filters; and HEPA filters.

^d The emission factor represents the average of the emission factors for the liquid injection incinerators tested with the various control devices specified in footnote c.

7.3.5 Regulatory Analysis

Organic emissions from hazardous waste incinerators are regulated under 40 CFR 246, Subpart O, promulgated on June 24, 1982.²⁰⁴ The standards require that in order for a hazardous waste incineration facility to receive a RCRA permit, it must attain a 99.99 percent destruction and removal efficiency (DRE) for each principal organic hazardous constituent (POHC) in the waste feed. Each facility must determine which one or more organic compounds, from a list of approximately 400 organic and inorganic hazardous chemicals (including benzene) in Appendix VIII of 40 CFR 261,²⁰⁵ are POHCs, based on which are the most difficult to incinerate, considering their concentration or mass in the waste feed. Each facility must then conduct trial burns to determine the specific operating conditions under which 99.99 percent DRE is achieved for each POHC.

In order to ensure 99.99 percent DRE, operating limits are established in a permit for each incinerator for the following conditions: (1) CO level in the stack exhaust gas, (2) waste feed rate, (3) combustion temperature, (4) an appropriate indicator of combustion gas velocity, (5) allowable variations in incinerator system design or operating procedures, and (6) other operating requirements considered necessary to ensure 99.99 percent DRE for the POHCs.

Additionally, Subpart O of 40 CFR 246 requires that hazardous waste incineration facilities achieve 99-percent emissions reduction of HCl (if HCl emissions are greater than 1.8 kg/hr [4.0 lb/hr]) and a limit of 180 milligrams per dry standard cubic meter (0.0787 grains per dry standard cubic foot) for PM emissions. These emission limits would require facilities to apply acid gas/PM control devices. As mentioned in Section 7.3.4, acid gas/PM control devices may result in partial control of emissions of organic compounds.

7.4 EXTERNAL COMBUSTION OF SOLID, LIQUID, AND GASEOUS FUELS IN STATIONARY SOURCES FOR HEAT AND POWER GENERATION

The combustion of solid, liquid, and gaseous fuels such as natural gas, oil, coal, and wood waste has been shown to be a minor source of benzene emissions. This section addresses benzene emissions from the external combustion of these types of fuels by stationary sources that generate heat or power in the utility, industrial/commercial, and residential sectors.

7.4.1 Utility Sector²⁰⁶

Fossil fuel-fired utility boilers comprise about 72 percent (or 1,696,000 million Btu/hr [497,000 megawatts (MW)]) of the generating capacity of U.S. electric power plants. The primary fossil fuels burned in electric utility boilers are coal, natural gas, and oil. Of these fuels, coal is the most widely used, accounting for 60 percent of the U.S. fossil fuel generating capacity. Natural gas represents about 25 percent and oil represents 15 percent of the U.S. fossil fuel generating capacity.

Most of the coal-firing capability is east of the Mississippi River, with the significant remainder being in the Rocky Mountain region. Natural gas is used primarily in the South Central States and California. Oil is predominantly used in Florida and the Northeast. Fuel economics and environmental regulations affect regional use patterns. For example, coal is not used in California because of stringent air quality limitations. Information on precise utility plant locations can be obtained by contacting utility trade associations such as the Electric Power Research Institute in Palo Alto, California (415-855-2000); the Edison Electric Institute in Washington, D.C. (202-828-7400); or the U.S. Department of Energy (DOE) in Washington, D.C. Publications by EPA/DOE on the utility industry are also useful in determining specific facility locations, sizes, and fuel use.

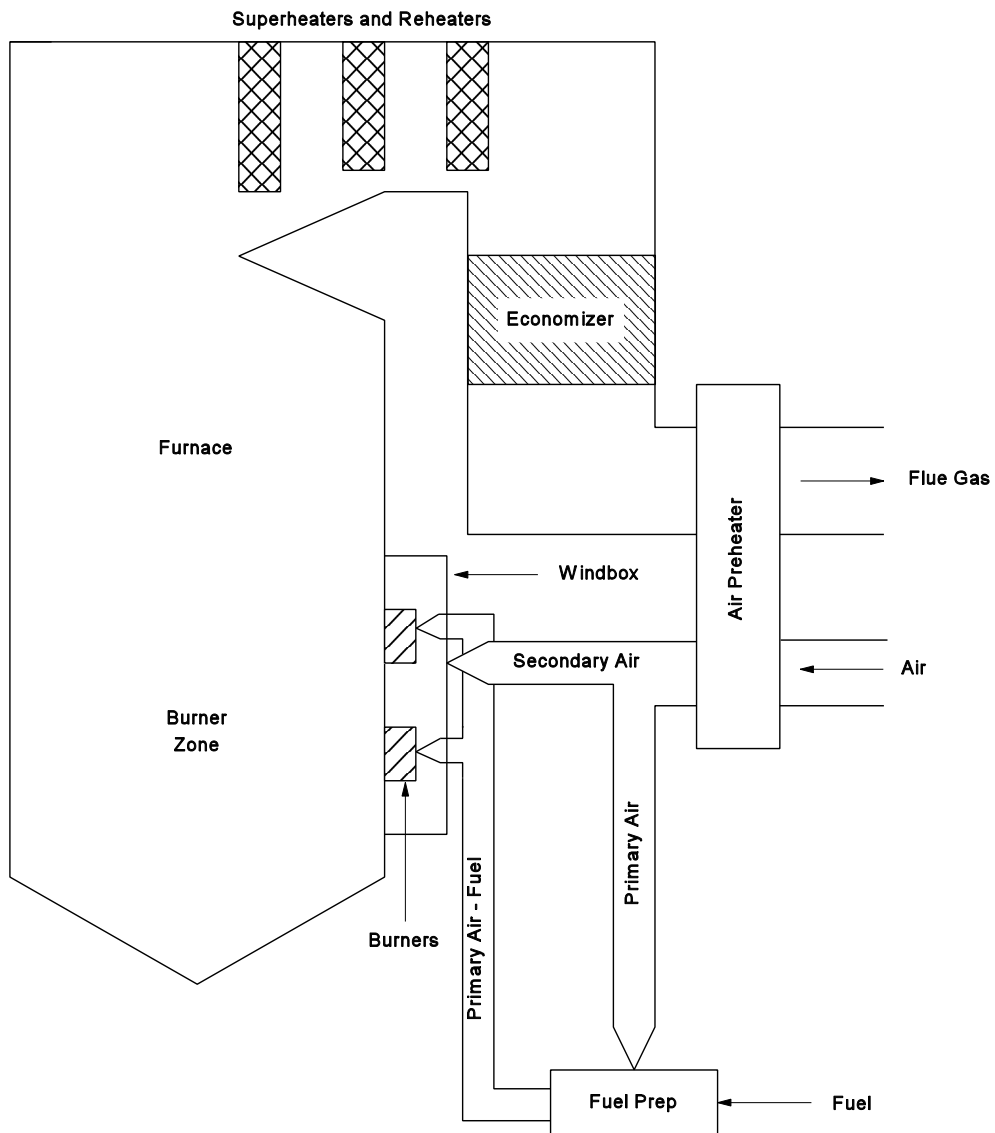
Process Description of Utility Boilers

A utility boiler consists of several major subassemblies, as shown in Figure 7-11.²⁰⁶ These subassemblies include the fuel preparation system, the air supply system, burners, the furnace, and the convective heat transfer system. The fuel preparation system, air supply, and burners are primarily involved in converting fuel into thermal energy in the form of hot combustion gases. The last two subassemblies are involved in the transfer of the thermal energy in the combustion gases to the superheated steam required to operate the steam turbine and produce electricity.²⁰⁶

Three key thermal processes occur in the furnace and convective sections of the boiler. First, thermal energy is released during controlled mixing and combustion of fuel and oxygen in the burners and furnace. Second, a portion of the thermal energy formed by combustion is adsorbed as radiant energy by the furnace walls. The furnace walls are formed by multiple, closely spaced tubes filled with high-pressure water that carry water from the bottom of the furnace to absorb radiant heat energy to the steam drum located at the top of the boiler. Third, the gases enter the convective pass of the boiler, and the balance of the energy retained by the high-temperature gases is adsorbed as convective energy by the convective heat transfer system (superheater, reheater, economizer, and air preheater).²⁰⁶

A number of different furnace configurations are used in utility boilers, including tangentially fired, wall-fired, cyclone-fired, stoker-fired, and FBC boilers. Some of these furnace configurations are designed primarily for coal combustion; others are designed for coal, oil, or natural gas combustion. The types of furnaces most commonly used for firing oil and natural gas are the tangentially fired and wall-fired boiler designs.²⁰⁷ One of the primary differences between furnaces designed to burn coal versus oil or gas is the furnace size. Coal requires the largest furnace, followed by oil, then gas.²⁰⁶

The average size of boilers used in the utility sector varies primarily according to boiler type. Cyclone-fired boilers are generally the largest, averaging about 850 to



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Figure 7-11. Simplified Boiler Schematic

Source: Reference 206.

1,300 million Btu/hr (250 to 380 MW) generating capacity. Tangentially fired and wall-fired boiler designs firing coal average about 410 to 1,470 million Btu/hr (120 to 430 MW); these designs firing oil and natural gas average about 340 to 920 million Btu/hr (100 to 270 MW). Stoker-fired boilers average about 34 to 58 million Btu/hr (10 to 17 MW).²⁰⁷ Additionally, unit sizes of FBC boilers range from 85 to 1,360 million Btu/hr (25 to 400 MW), with the largest FBC boilers typically closer to 680 million Btu/hr (200 MW).²⁰⁶

Tangentially Fired Boiler--The tangentially-fired boiler is based on the concept of a single flame zone within the furnace. The fuel-to-air mixture in a tangentially fired boiler projects from the four corners of the furnace along a line tangential to an imaginary cylinder located along the furnace centerline. When coal is used as the fuel, the coal is pulverized in a mill to the consistency of talcum powder (i.e., at least 70 percent of the particles will pass through a 200-mesh sieve), entrained in primary air, and fired in suspension.²⁰⁸ As fuel and air are fed to the burners, a rotating “fireball” is formed to control the furnace exit gas temperature and provide steam temperature control during variations in load. The fireball may be moved up and down by tilting the fuel-air nozzle assembly. Tangentially fired boilers commonly burn coal (pulverized). However, oil or gas may also be burned.²⁰⁶

Wall-Fired Boiler--Wall-fired boilers are characterized by multiple individual burners located on a single wall or on opposing walls of the furnace. Refer to Figure 7-12 for a diagram of a single wall-fired boiler.²⁰⁶ As with tangentially fired boilers, when coal is used as the fuel, the coal is pulverized, entrained in primary air, and fired in suspension. In contrast to tangentially fired boilers, which produce a single flame envelope or fireball, each of the burners in a wall-fired boiler has a relatively distinct flame zone. Depending on the design and location of the burners, wall-fired boilers consist of various designs, including single-wall, opposed-wall, cell, vertical, arch, and turbo. Wall-fired boilers may burn (pulverized) coal, oil, or natural gas.²⁰⁶

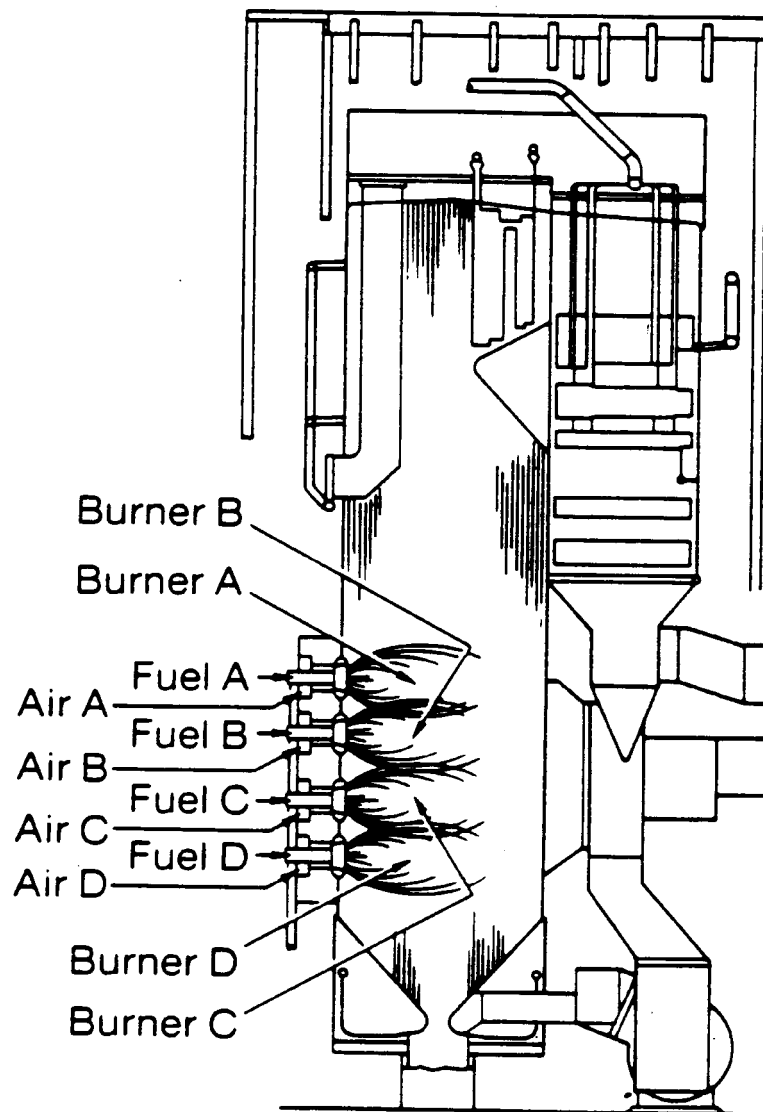


Figure 7-12. Single Wall-fired Boiler

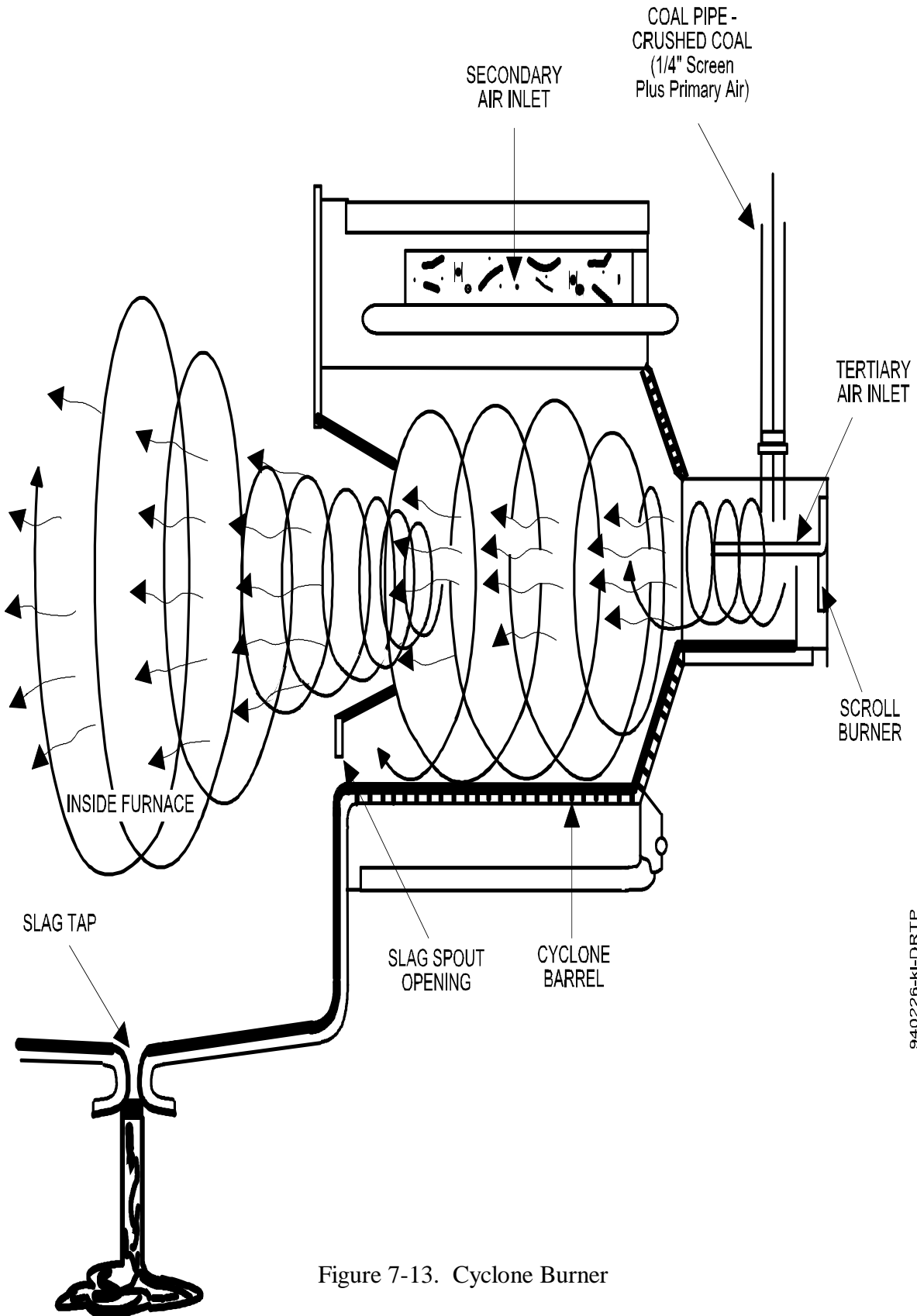
Source: Reference 206.

Cyclone-Fired Boiler--As shown in Figure 7-13, in cyclone-fired boilers, fuel and air are burned in horizontal, cylindrical chambers, producing a spinning, high-temperature flame. When coal is used, the coal is crushed to a 4-mesh size and admitted with the primary air in a tangential fashion. The finer coal particles are burned in suspension and the coarser particles are thrown to the walls by centrifugal force.²⁰⁷ Cyclone-fired boilers are almost exclusively coal-fired and burn crushed rather than pulverized coal. However, some units are also able to fire oil and natural gas.²⁰⁶

Fluidized-Bed Combustion Boiler--Fluidized-bed combustion is a newer boiler technology that is not as widely used as the other, conventional boiler types. In a typical FBC boiler, crushed coal in combination with inert material (sand, silica, alumina, or ash) and/or sorbent (limestone) are maintained in a highly turbulent suspended state by the upward flow of primary air from the windbox located directly below the combustion floor. This fluidized state provides a large amount of surface contact between the air and solid particles, which promotes uniform and efficient combustion at lower furnace temperatures--between 1,575 and 1,650°F (860 and 900°C) compared to 2,500 and 2,800°F (1,370 and 1,540°C) for conventional coal-fired boilers. Fluidized bed combustion boilers have been developed to operate at both atmospheric and pressurized conditions. Refer to Figure 7-14 for a simplified diagram of an atmospheric FBC.²⁰⁶

Stoker-Fired Boiler--Rather than firing coal in suspension, mechanical stokers can be used to burn coal in fuel beds. All mechanical stokers are designed to feed coal onto a grate within the furnace. The most common stoker type of boiler used in the utility industry is the spreader-type stoker (refer to Figure 7-15 for a diagram of a spreader type stoker fired-boiler).²⁰⁶ Other stoker types are overfeed and underfeed stokers.

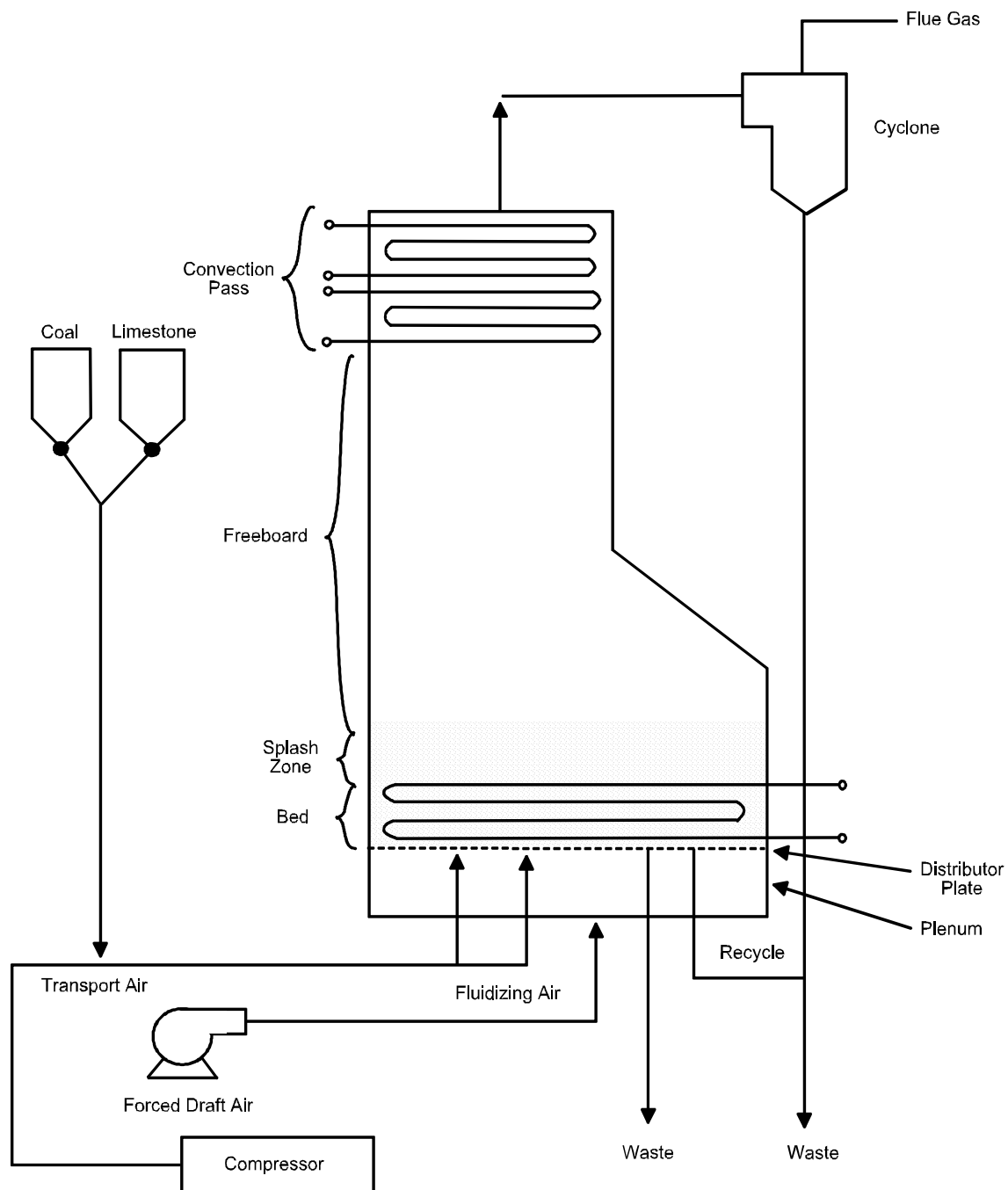
In spreader stokers, a flipping mechanism throws crushed coal into the furnace and onto a moving fuel bed (grate). Combustion occurs partly in suspension and partly on the grate.²⁰⁸ In overfeed stokers, crushed coal is fed onto a traveling or vibrating grate from an adjustable gate above and burns on the fuel bed as it progresses through the furnace.



940226-KI-DRTP

Figure 7-13. Cyclone Burner

Source: Reference 206.



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Figure 7-14. Simplified Atmospheric Fluidized Bed Combustor Process Flow Diagram

Source: Reference 206.